Units and Conversions for Stream Restoration Projects

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Complexity	***Value as a Planning Tool***	***Cost***
Low — Moderate — High	Low — Moderate — High	Low — Moderate — High

OVERVIEW

The conversion from U.S. Customary units to metric units has become increasingly important to nearly every practitioner in stream restoration. As more and more projects are specified in metric units and more and more supplies become available in metric sizes, users need to be conversant in the International System of measurements (SI) or what is commonly called the metric system of measurement. The SI standards are actually a set of units adopted as a standard by the International Bureau of Weights and Measures (BIPM). IEEE and ASTM most recently adopted this standard in the United States in 1992-93 as explained in IEEE/ASTM SI 10-1997. The standards are designed to be a standardized set of units that mostly eliminate confusion regarding the various measurements and units. The IEEE/ASTM standards are based on *Le Système International d'Unités* published by the BIPM and include modifications from 1995.

The purpose of this technical note is to guide the user to the units of measurement commonly used in stream restoration projects and to provide conversions between U.S. Customary and International System (SI) units as well as from SI to U.S. Customary. This technical note is accompanied by an Excel spreadsheet with conversions for both U.S. Customary to SI and SI to U.S. Customary.

The spreadsheet is also available for download via the Internet at either www.el.usace.army.mil/???/conversion.xls or from www.riverspace.com/dengari/conversions.xls.

Additionally the conversions are included in the text portion of this technical note for easy reference in a publication small enough to carry to the field for those times when the practitioner is away from the computer.

UNITS OF MEASUREMENT FOR STREAM RESTORATION PROJECTS

The most common units of measure for stream restoration projects involve length, area, volume, flow rates, density, weight, pressure, temperature, and others. All of the variables

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are based on units of mass, length, and time and occasionally measurement-specific units for units specific to a measurement (temperature, for example). The conversions are shown here in their base units to facilitate conversions where the exact factor may not be present in the tables and spreadsheet. The relation between various odd U.S. Customary units is also given to facilitate conversions among the various U.S. Customary units when necessary. Some of the units (e.g., chains) are confusing because two differing lengths use the same common name. The type of chain being used can usually be determined by calculating the area involved or by comparison to other lengths involved. Often one type of chain is used throughout an area for a measurement, and the other can be eliminated through the questioning of a surveyor or a county recorder's office.

Conversions are given to a high number of significant digits, not because they are needed in most applications; rather, they can provide accuracy when needed. The user should keep in mind the accuracy of measurements in the field and not assume that because the conversion factor has a high number of significant digits the converted measurement will also be accurate to the same number of decimal places.

The conversion factors may be divided into several basic types of measurements based on a) simple length conversion, such as length, area, and volume; b) length-time conversion, such as velocity and flow rates; c) and those involving additional factors, such as weight, pressure, power, temperature, stiffness, and density. Some of the factors, while grouped together, are rather unrelated (e.g., area density of plants and the volume density of materials). All of the conversions are included in both the paper and spreadsheet. Exact conversion factors are shown in **bold**.

FACTOR OF 10 MULTIPLES IN SI

The SI system specifies how multiples of units are to be named. These values are shown in Table 1 for ease of reference. For further information see the IEEE/ASTM Standard SI 10-1997 (American National Standards Institute 1997). A restoration project will not likely use the tera and pico prefixes.

Table 1. Prefixes of SI Units

Factor	Prefix	Symbol
10^{12} = 1,000,000,000,000	Tera	T
10^{9} = 1,000,000,000	Giga	G
10^{6} = 1,000,000	Mega	M
10^{3} = 1,000	Kilo	k
10^{2} = 100	Hecto	
10^{1} = 10	Deka	
10^{-1} = 0.1	Deci	
10^{-2} = 0.01	Centi	c
10^{-3} = 0.001	Milli	m
10^{-6} = 0.000001	Micro	μ
10^{-9} = 0.000,000,001	Nano	n
10^{-12} = 0.000,000,000,001	Pico	p

LENGTH CONVERSIONS

Length conversions are probably the simplest because of dual labeling of items from rulers to roadway signs, and the most easily remembered. To use the factors simply multiply the units being converted by the conversion factor shown to obtain the desired units (Table 2).

Table 2. Length Conversion Factors for U.S. Customary to SI

To Convert From	Multiply By The Conversion Factor	To Obtain
Inches (in)	**2.5400**	Centimeters (cm)
Feet (ft) (12 in)	**0.3048**	Meters (m)
Yards (yd) (3 ft)	**0.9144**	Meters (m)
Miles (mi) (5280 ft)	1.6094	Kilometers (km)
Fathom (6 ft)	**1.8288**	Meters (m)
Rod (16.5 ft)	**5.0292**	Meters (m)
Engineer's Chain (100 ft) (also 100 links)	**30.48**	Meters (m)
Gunter's Chain (66 ft) (also 4 rods)	**20.1168**	Meters (m)

To convert from SI to U.S. Customary, divide by the conversion factor.

The next series of conversions (Table 3) involve area or length squared (l^2). These factors are obtained by simply squaring the length conversions above.

Table 3. Area Conversion Factors for U.S. Customary to SI

To Convert From	Multiply By The Conversion Factor	To Obtain
Square Inches (in^2)	**6.4516**	Square Centimeters (cm^2)
Square Feet (ft^2)	0.0929	Square Meters (m^2)
Square Yards (yd^2)	0.8361	Square Meters (m^2)
Acres (ac) (43,560 ft^2)	0.4047	Hectares (ha) (10,000 m^2)
Acres (ac)	4046.87	Square Meters (m^2)
Sq. Miles (mi^2) (640 acres)	2.590	Square Kilometers (km^2)

To convert from SI to U.S. Customary, divide by the conversion factor.

The next length-based conversions involve volume or l^3. These conversions are the cube of the base conversion for length. Several common but unique U.S. Customary units, such as acre-feet, are also included. Also included are several smaller volume measurements, such as those required in mixing sprays or other application solutions in restoration projects (Table 4).

Table 4. Volume Conversion Factors for U.S. Customary to SI

To Convert From	Multiply By The Conversion Factor	To Obtain
Cubic Inches (in^3)	16.387	Cubic Centimeters (cm^3)
Cubic Inches (in^3)	1.6387E-05	Cubic Meters (m^3)
Cubic Feet (ft^3)	0.028317	Cubic Meters (m^3)
Cubic Yards (yd^3)	0.7646	Cubic Meters (m^3)
Acre Feet (ac-ft)	1223.49	Cubic Meters (m^3)
Gallons (gal)	3.7854E-03	Cubic Meters (m^3)
Gallons (gal)	3.7854	Liters (L)
Fluid Ounces (US) (oz)	29.574	Milliliters (mL) (cc)
Fluid Ounces (US) (oz)	2.9574E-05	Cubic Meters (m^3)
Quarts (US Dry) (qt)	1.1012E-03	Cubic Meters (m^3)
Quarts (US Dry) (qt)	1.01012	Liters (L)
Quarts (US Liquid) (qt)	9.4635E-04	Cubic Meters (m^3)
Quarts (US Liquid) (qt)	.94635	Liters (L)
Bushels (bu)	.03524	Cubic Meters (m^3)

To convert from SI to U.S. Customary, divide by the conversion factor.

VELOCITY AND FLOW RATE CONVERSIONS

Conversion of velocity and flow rates involved the conversion of units of time and length. Because time units are the same in both systems, the only units to be converted are again those dealing with the lengths involved. The only difference between flow rate and velocity is the number of length units involved (i.e., l versus l^2 or l^3).

Table 5. Velocity and Flow Rate Conversions for U.S. Customary to SI

To Convert From	Multiply By The Conversion Factor	To Obtain
Flow Rates		
Cubic Feet/Second (cfs) (ft^3/sec)	0.028317	Cubic Meters/Second (m^3/sec)
Gallons/Minute (gpm)	6.3090E-05	Cubic Meters/Second (m^3/sec)
Gallons/Minute (gpm)	0.063090	Liters/Second (L/s)
Gallons/Day	4.381E-05	Liters/Second (L/s)
Velocity		
Feet/Second (fps)	**0.3048**	Meters/Second (m/s)
Miles per Hour (mph)	1.6093	Kilometers/Hour (km/hr)
Miles per Hour (mph)	**0.44704**	Meters/Second (m/s)

To convert from SI to U.S. Customary, divide by the conversion factor.

Given the need to apply treatments to areas, converting area per unit time may be necessary. Conversion is accomplished by changing the area from one set of units to the other while keeping the time-based ones constant. For example, to convert from acres per day to hectares per day, one would simply convert acres to hectares by multiplying the acres value by 0.404704 to convert to hectares per day. If the time bases are different, they must be adjusted. For example if the units are in acres per day and hectares per hour are needed, convert one of the units (e.g., days to hours) and divide the acres per day rate by 24. The result would then be in hectares per hour. This same approach can be used in any conversion if the exact conversion sought is not available in the tables or spreadsheet.

In conversions to SI, the multitude of U.S. Customary units confuses the conversion issue, rather than the number of metric values.

WEIGHT, PRESSURE, AND STIFFNESS CONVERSIONS

Conversions of weight, pressure and stiffness involve multiple units of measurement. These conversions involve not only length (l) but also weight or force. The involvement of gravity also complicates the matter because pounds and kilograms are often used interchangeably to mean either mass or weight, which are distinctly different quantities. This section addresses both the conversions involving weight (i.e., gravity is included) and mass.

Various measures can be converted as shown in Table 6, based on the assumption that pounds in common use include gravity and are thus representative of weight (i.e., pounds force). In the SI system, Newtons represent weight in accordance with the IEEE/ASTM Standard SI 10-1997. The use of kilograms to represent weight is not recommended; however, conversions between U.S. Customary units of mass and SI mass units are included to allow conversion between common units. A REMINDER: WEIGHT AND FORCE IN THE SI SYSTEM ARE IN NEWTONS RATHER THAN KILOGRAMS. If suppliers are using both pounds and kilograms as units of weight, the conversion from pounds mass to kilograms mass can be used to represent weight on both sides because the units of gravity can be ignored (or included) on both sides of the conversion without causing an error. Only when both units do not contain the gravity term would problems arise. Users should become familiar with the proper use of the SI terms.

POWER, TEMPERATURE AND DENSITY CONVERSIONS

The conversions for power, temperature and density are grouped primarily due to their differing from the classifications above. Temperature is normally measured either in degrees Fahrenheit or degrees Celsius, even though the IEEE/ASTM SI 10-1997 states that temperature should be measured in degrees Kelvin. The relation between degrees Kelvin (K) and Celsius (C) is simple, $^{o}K = {}^{o}C+273.15$.

Temperatures are normally reported in either degrees Celsius or degrees Fahrenheit in common usage; only in laboratory tests are temperatures reported in Kelvin.

Table 6. Weight, Pressure and Stiffness Conversion factors for U.S. Customary to SI

To Convert From	Multiply By The Conversion Factor	To Obtain
Weight and Mass		
Ounces (mass) (oz)	28.3495	Grams (g) (mass)
Ounces (force/weight) (oz)	0.2780	Newtons (N)
Pounds (mass) (lbm)	0.4536	Kilograms (kg)
Pound (force/weight) (lbf)	4.4482	Newton (N)
Short Tons (2000 lb)	907.1847	Kilograms (kg)
Long Tons (2240 lb)	1016.047	Kilograms (kg)
Pressure		
lbf/sq. in. (psi)	6894.757	Pascals (Newtons/ Square Meter) (Pa)
lbf/sq ft (psf)	47.88026	Pascal (Pa)
Feet of water (ft)	2989.07	Pascal (Pa)
Feet of water (ft) (2.31 ft = 1 psi)	2.98907	Kilopascals (kPa)
Stiffness		
Stiffness Modulus E (psi)	6894.7570	Pascals (Pa) (Newtons/Square Meter)

To convert from SI to U.S. Customary, divide by the conversion factor.

Density of materials are specified in mass units, rather than force units; thus, material density in pounds per cubic foot or cubic yard are converted to kilograms per cubic meter rather than Newtons per cubic meter (Table 7), which also applies to the conversion for weights measured in tons in Table 6.

Table 7. Power Temperature and Density Conversions for U.S. Customary to SI

To Convert From	Multiply By The Conversion factor	To Obtain
Power		
Horsepower (550 ft-lb/sec)	745.6999	Watts (W)
Temperature		
Degrees Fahrenheit (°F)	(Tf-32)/1.8	Degrees Celsius (°C)
Density		
Number /Square Foot	10.7639	Number/ Square Meter
Pounds/Cubic Foot (lb/ft^3)	16.01846[1]	Kg/m^3
Pounds/Cubic Foot (lbf/ft^3)	157.085	$Newtons/m^3$
Pounds/Cubic Yard (lb/yd^3)	0.59328	Kg/m^3
Pounds/Cubic Yard (lbf/yd^3)	5.8177[2]	$Newtons/m^3$

To convert from SI to U.S. Customary, divide by the Conversion factor

1 This factor is obtained by combining the conversion factors for lb to Newton and that for ft^3 to m^3. (4.4482/0.028317=157.085) (See Tables 2 and 4.)

2 This factor is obtained by combining the conversion factors for lb to Newton and that for yd^3 to m^3. (4.4482/0.7646=5.8177) (See Tables 2 and 4.)

The difference between kg/m^3 and N/m^3 for the same measurement should be equal to the acceleration of gravity (9.80665 m/s^2).

SI TO U.S. CUSTOMARY CONVERSIONS

The factors for converting from SI to U.S. Customary are simply the inverse (i.e., 1.0/ factor) of the conversion factor used to convert from U.S. Customary to SI. Thus to convert from the SI units to U.S. Customary units simply divide the SI value by the conversion factor to obtain the U.S. Customary units. The accompanying spreadsheet has a section for the conversion from SI to U.S. Customary as well as the section for converting U.S. Customary units to SI units.

SUMMARY AND CONCLUSIONS

The conversion of units has caused large amounts of confusion throughout history and the conversion from U.S. Customary to SI units is no different. A significant number of problems have arisen from the historical use of units for mass and weight interchangeably in both systems of measurement. An additional problem is the multitude of units used in the U.S. Customary system (e.g., feet, yards, rods, fathoms, chains, and two varieties of miles (statute and nautical)), all to measure distance between two points. While all of these units are useful to various practitioners, they only add to the confusion associated with the U.S. Customary to SI conversion.

The use of mass units instead of the proper weight units continues to be a major problem. Weight is still often reported in kilograms rather than in Newtons and the use of pounds interchangeably for both mass and weight adds confusion to both sides of the conversion process. Weight specified in both pounds and kilograms on consumer products and even a cursory examination will reveal that both units are being used to represent weight rather than mass.

ADDITIONAL REFERENCES AND CONVERSION FACTORS

Additional references are available both on-line and in printed texts. Two of the resources are as follows and nearly every technical resource has at least a small table of conversion factors. Numerous Web sites are also available to convert from one system of units to the other.

BIBLIOGRAPHY

American National Standards Institute. (1997). "Standard for Use of the International System of Units (SI): The Modern Metric System." IEEE/ASTM SI 10-1997, American National Standards Institute, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, Available for download (Cost $50.00) from http://www.astm.org.

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APPLICABILITY AND LIMITATIONS

Techniques described in this technical note are generally applicable to stream restoration projects.

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